Semi-annual EOS Contract Report

Period: January 1 - June 30, 2003

Remote Sensing Group (RSG), Optical Sciences Center (OSC) at the University of Arizona

Principal Investigator: K. Thome

Contract Number: NAS5-31717

Summary: During this six-month period, Remote Sensing Group personnel attended meetings related to MODIS and ASTER, including the ASTER and MODIS Science Team meetings. Further field campaigns were held for the Aqua and Terra MODIS sensors as well as the ASTER sensor on Terra. The ASTER sensor continues to show large differences from predicted values in the VNIR due to probable calibration changes in orbit and in the SWIR due to the optical crosstalk effect. Results from MODIS on Terra show that the calibration of this sensor is known to within the accuracy of the vicarious approaches. Both results have been verified through comparisons with ETM+. Laboratory work continues to show that the accuracy of the group's spectral response measurements has been improved through the addition of an optical wedge.

Introduction: This report contains four sections. The first three sections present different aspects of work performed under our contract: 1) Science team support activities; 2) Calibration laboratory; and 3) Field experiments and equipment. The fourth section contains information related to faculty, staff, and students.

Science Team Support Activities: This section refers to all work performed in support of MODIS and ASTER team activities as well as work performed for other sensor teams. Over the past six months this included the attendance at team and other related meetings and completing assigned action items. In MODIS-related activities, S. Biggar participated in a large fraction of the weekly teleconference calls coordinated by the MODIS Characterization and Support Team. ASTER-related activities consisted of attendance by Biggar and K. Thome at the ASTER Science Team Meeting held in Tokyo, Japan from May 21-22 as well as the US ASTER Science Team Meeting held May 20. Biggar presented recent results related to the SWIR crosstalk effect as well as preliminary results from the recent lunar calibration maneuver at both meetings. Thome presented the vicarious calibration results of ASTER as well as chairing the Atmospheric Correction Working Group Meeting where he presented the new MISR aerosol model that is to be implemented into the ASTER atmospheric correction.

In related activities, Thome traveled to Zurich, Switzerland in January where he presented the talk entitled "The Vicarious Calibration of Large Footprint Sensors" at the University of Zurich. Thome also presented the talk entitled "Radiance validation of the solar reflective bands of MODIS" to the Institute of Atmospheric Physics at the University of Arizona. In February, Thome attended the AVIRIS Conference in Pasadena February 24-27 and presented the "Use of AVIRIS in the cross-calibration of Earth Science Enterprise sensors." Finally, Biggar and Thome presented talks related to the preflight and inflight calibration of ASTER at the ASTER Users Workshop held in Arcadia, California April 29-30.

Calibration Laboratory: This section describes the laboratory work used to ensure that the results from the field measurements are consistent with each other and to NIST-standards. To this end, the RSG relies on a set of cross-calibration radiometers (CCRs) that cover the wavelength region from 400 to 2500 nm and are ultrastable with respect to temperature and time. These radiometers were used to provide an independent calibration and cross-calibration of the calibration facilities used for the preflight calibration of EOS sensors. In addition, the RSG has developed a calibration laboratory that includes the capability of absolute radiometric calibration using NIST primary standards of spectral irradiance, a 40-inch spherical integrating source, a collimator for field of view measurements, and a double-pass monochromator for spectral characterization.

The two transfer radiometers mentioned above were originally designed to measure the radiance of large integrating spheres. One radiometer covers the range of about 412 nm to 870 nm, referred to as the VNIR CCR and the second covers the shortwave infrared out to about 2400 nm, the SWIR CCR. The spectral bandpass of the radiometers is controlled by interference filters which mimic the spectral response of various MODIS and ASTER bands. The VNIR CCR filters are similar to some of the ocean bands of MODIS and fall in the wider VNIR bands of ASTER and MISR.

The VNIR CCR has silicon detectors arranged in a three detector "trap" configuration. The trap ensures that over 99% of the light incident on the input aperture of the detector set is absorbed. Therefore, if the limiting apertures and the transmittance of the filters are well known, the calibration of the radiometer can be calculated. The filters were measured with an Optronic OL750 double monochromator with an Optronic transmittance accessory. The radiometer was then calibrated with a set of standards of spectral irradiance (FEL type, calibrated, quartz-halogen, 1KW lamps). The calibration was also calculated but the calibration based on measuring a known lamp did not agree well with the computed calibration, being between about 2 and 12 percent different, depending on the band. As the estimated uncertainty of the measured calibration is less than 2.5% and the computed calibration should be even better, the difference was troubling. Figure 1 presents the difference in calibration (calculated - measured) for the transfer radiometer based on four different measurements in late 1995 and early 1996.

In order to reduce the errors in the measurement of interference filters, a glass wedge was inserted in front of the Optronic detector to prevent reflections from the detector from falling on the filter. Measurements with this wedge have been reported previously and the results of using these measurements in the calculation of the calibration of the VNIR CCR are shown in Figure 2. The

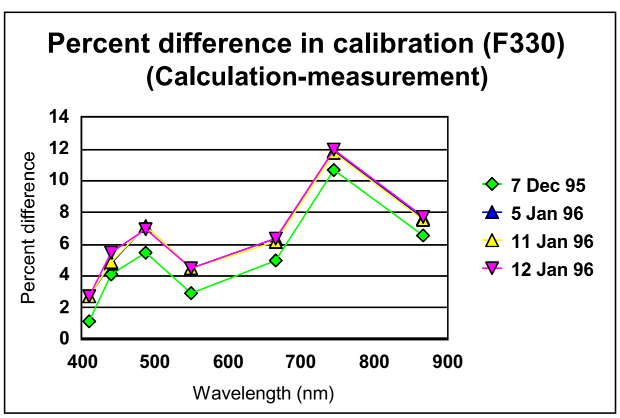

Figure 1 Percent difference between calculated and measured calibration of transfer radiometer

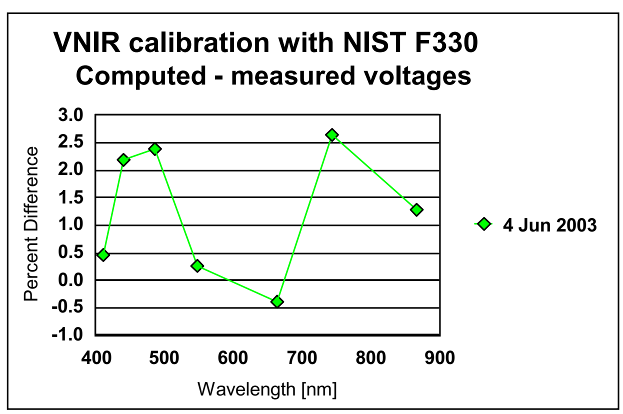

Figure 2 Calibration differences using improved transmittance measurements

differences are reduced in all bands and the current difference is within the combined expected uncertainties of the two methods. There may still be some minor systematic errors - we expect to evaluate that after we take delivery of a newly calibrated NIST lamp and make both irradiance and radiance based calibrations of the transfer radiometer.

The work with the CCRs has led the remote sensing group to design and begin construction of a stable monitor radiometer for the Robotic Lunar Observatory (ROLO) at USGS Flagstaff. ROLO is making a set of lunar radiance measurements to allow the use of the moon as a calibration target for spacecraft optical sensors such as SeaWiFS, MODIS, ASTER, ALI, and Hyperion. ROLO uses stars and a lamp illuminated diffuser as calibration sources along with a new collimated source that will be used in the next few months to help with calibration. At present there are differences between the calibration using the lamp/diffuser and the stars which are larger than desired.

In order to ensure that the lamp illuminated diffuser and the source for the collimator are stable, a simple but stable monitor radiometer will be used. This radiometer design was completed and construction was started. As the radiometer must operate over a wide temperature range, the radiometer uses a pair of invar apertures held apart by invar spacers to control the throughput. The light passing through the pair of apertures falls on a high quality ion-assisted deposition interference filter simulating the 4th band of the Landsat ETM+ sensor. The filtered light then falls on a Hamamatsu detector with an integrated operational amplifier. The rear aperture, filter, detector/amplifier and electronics are contained in a thermally controlled enclosure made from oxygen-free, high conductivity copper. The enclosure temperature will be maintained by a TE cooler controlled by an ILX TE cooler controller. The combination of invar apertures and metering rods and thermal control of the filter, detector, and electronics should result in a stable monitor.

The aperture diameters are sized to view the center six inches of the calibration diffuser and also to allow direct viewing of the collimator prime focus source. The monitor will be mounted on the ROLO telescope mount for viewing the diffuser. The monitor will be placed directly in front of and close to the prime focus source for that application. The radiometer front aperture can be removed and replaced by a lens to allow measurement of the radiance from the collimator. It will be mounted on a collimator strut for that final configuration. The normal operating mode will be to monitor the diffuser. In this mode, the monitor is pointed at the diffuser by the telescope tracking mount.

The primary goal of such an effort is to develop a consistent calibration for ROLO that is NIST traceable with well-understood uncertainties. This will allow the lunar data collected by ASTER and MODIS, as well as other ESE sensors, to be compared with the vicarious and onboard calibrator results to determine the radiometric calibration of each sensor. In addition, accurate knowledge of the moon's radiance as a function of time will allow cross-calibration and cross-comparison of a variety of sensors across multiple platforms.

Field Experiments and Equipment: The objectives of the field experiments are to test new equipment, determine needed improvements, develop and test retrieval algorithms and code, and monitor existing satellite. Numerous field campaigns were undertaken during the reporting period related to both ASTER and MODIS. A total of seven field experiments took place during the reporting period. Of these, the most disappointing trip was March 15-20 to Railroad Valley and Ivanpah Playa for a nadir overpass of Terra at Railroad Valley on March 16 and a near-nadir overpass of Aqua on March 18. Unfortunately both days were cloudy and no useful data were collected. Similar poor weather conditions were also encountered on May 3 for a nadir overpass of Terra during a May 2-4 campaign to both Ivanpah and Railroad Valley.

Other campaigns during the period were more successful beginning with the first trip in 2003 taking place January 17-20 with K. Canham, W. Garland, and Thome doing the data collection. The overpasses for this trip related to our EOS work were a 11-degree off-nadir view of Railroad Valley Playa on January 18 by Terra MODIS, a 27-degree view by Aqua MODIS of Railroad Valley on January 19, and a nadir view by ASTER on January 20 at Ivanpah Playa. The weather was excellent for both MODIS overpasses at Railroad Valley but uncooperative for the ASTER overpass on January 20. The Aqua MODIS results are included below and the Terra MODIS data are currently still being processed at the time of this report.

The January campaign was followed up with a trip taking place February 20-23 with C. Cattrall, T. Chen, and Thome participating. As has been noted in previous reports, trips to the Railroad Valley test site have been taking place roughly every month to allow for maintenance of the RSG's Cimel sunphotometer at the site as well as downloading meteorological data from a weather station that the group has installed there. Results from this weather station are described more below. The primary goals of the February trip were overpasses of ASTER at Ivanpah Playa on February 21 and Aqua MODIS on February 22 with both overpasses being nadir views. Both data sets have been processed and are included in the results described below.

After the unsuccessful trip in March that included J. Czapla-Myers, W. Garland, D. Moyer, and Thome that was timed to coincide with the University of Arizona's spring break, a trip in early April was made. This April campaign took place April 9-12 with N. Anderson, Cattrall, and Q. Sanford collecting data. While the weather was not perfect for the collections, with cirrus clouds present on both the nadir look by ASTER on April 10 at Ivanpah and the nadir look by Aqua MODIS on April 11 at Railroad Valley, data collections were successful on both dates. The results of these data are shown below.

The last two campaigns during the reporting period were May 25-30 and June 24-29. The May campaign consisted of Cattrall, Czapla-Myers, Chen, Garland, and Thome and was to both Ivanpah Playa and Railroad Valley Playa. Successful collections for an 11-degree look by Terra MODIS on May 26 and a 27-degree look by Aqua MODIS at Railroad Valley and a nadir look by ASTER at Ivanpah on May 28 made the trip reasonably successful, though weather did not cooperate with the attempted calibration of Aqua MODIS on May 29 at Railroad Valley. The June campaign was to Ivanpah only and included Anderson, Moyer, Sanford, and Thome. The primary work for this campaign was for the DOE sensor MTI and the trip was funded by Sandia National Laboratory. However, the campaign afforded the opportunity to calibrate ASTER on the 29th. The MODIS data from the May campaign are included in the results below, but the ASTER results still await arrival of the imagery to complete the processing.

The results of the above field campaigns for ASTER have all been processed though the imagery from the sensor were available for only the February 21 overpass data Level 1B and for this date plus April 10. In addition, Level 1A data from September 21, 2002 were located during the period and has been added to the results. At the Level 1A processing level, the conclusion is that degradation seen in past work appears to have slowed. This is evident in band 1 results shown in Figure 3 where the last two points in the figure are from the current processing during the reporting period. The primary issue is that the onboard calibrators continue to show degradation of the VNIR bands. Further work is planned to evaluate this issue. An interesting outcome of the continued degradation seen in the onboard calibrators is that the Japanese Science Team continues to change the calibration coefficients with time. Thus, the bias seen previously in VNIR bands is now absent (see Figure 4).

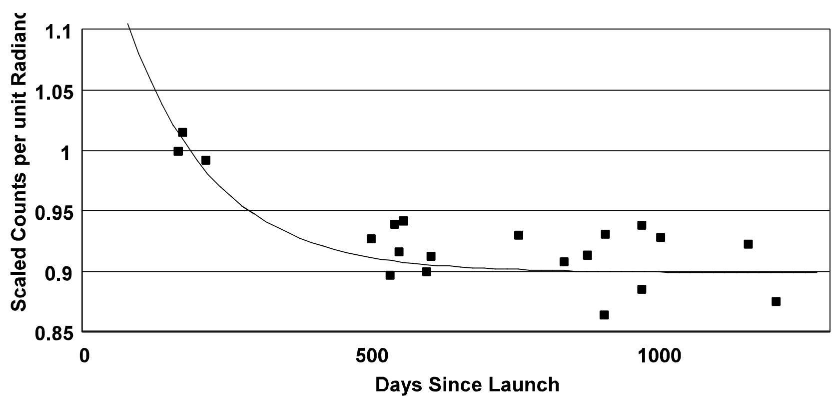

Figure 3. Level 1A results for ASTER band 1including two most recent data points. Results are scaled to June 4, 2000 data set and indicate relative calibration over time. Curve fit is an exponential decay based on least squares fit to the data.

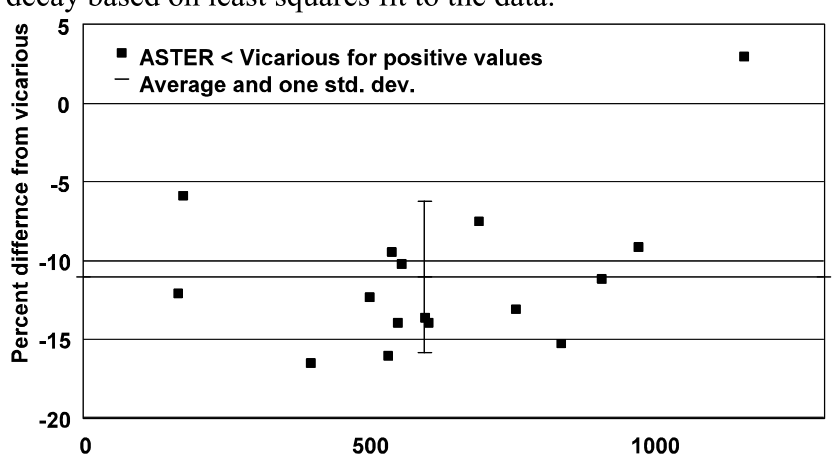

Figure 4. ASTER Band 1 Level 1B percent difference from vicarious prediction. Note “anomalous” from Feb. 21, 2002.

A large amount of the focus of efforts during the reporting period were devoted to understanding the early results from Aqua MODIS. Figure 5 summarizes the results for Aqua MODIS for all bands that do not suffer from saturation over the Railroad Valley test site. The results shown in the figure are the percent differences between the vicarious predictions and the reported radiance as a function of date for all of the bands of interest. Figure 6 shows the same results except gives the percent differences as a function of band rather than date. The results from early in the mission indicate significant differences between the reported and predicted radiances. This difference then decreases dramatically for all data sets after September 22.

It is not clear at this point what would cause this effect, but data sets from other sensors in July, August, and September indicate that the ground data were not anomalous. Figure 7 shows that data

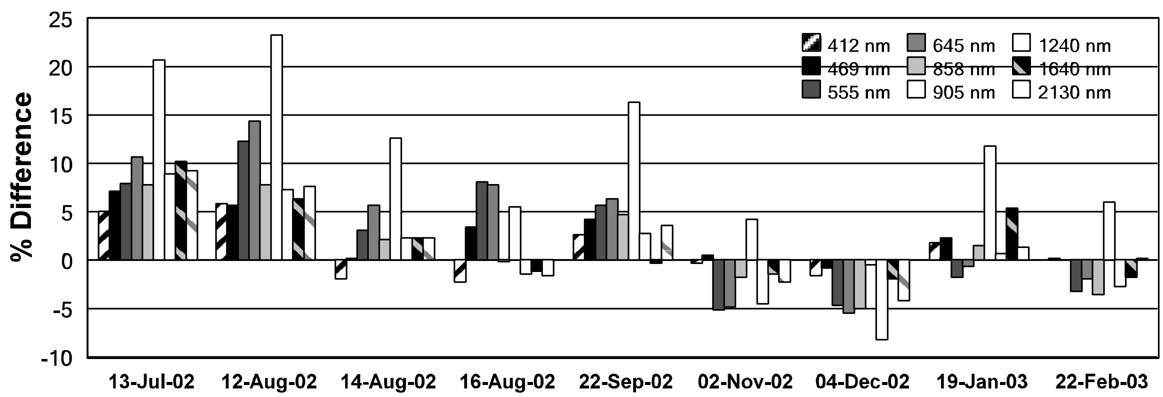

Figure 5. Summary of Aqua MODIS results from Railroad Valley Playa using the reflectance-based approach. Postive percent differences indicate that the reported radiances exceed the predicted values.

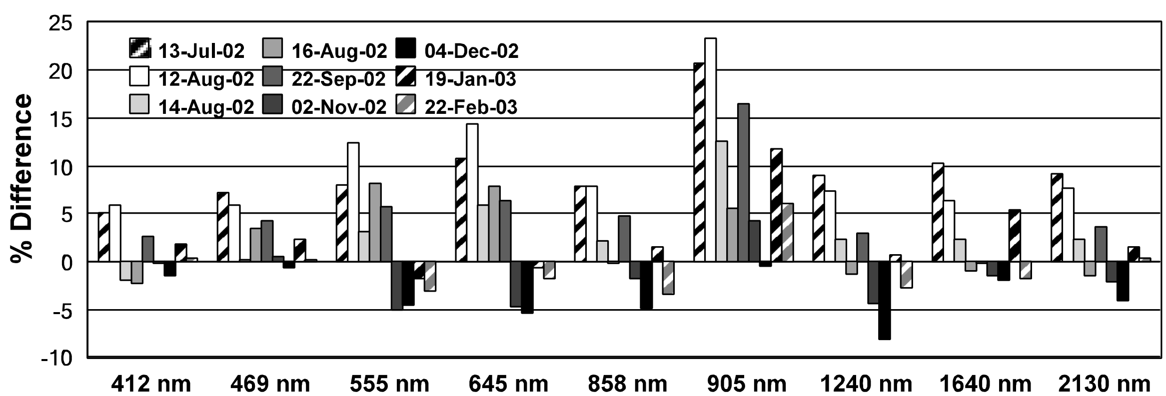

Figure 6. Same as Figure 5 except results are arranged to show percent differences for all dates for a given band

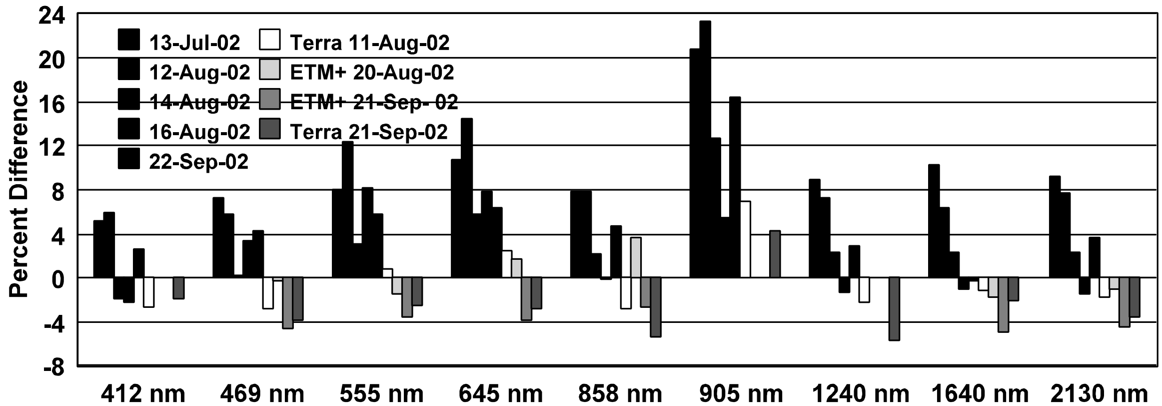

Figure 7. Results from Aqua MODIS from July, August, and September 2002 with ETM+ and Terra MODIS results for the same period.

collected for other sensors during this same time period are clearly different from the results obtained for Aqua MODIS. While the argument can be made that there is a change in equipment, surface parameterization, etc. between the morning and afternoon overpass periods, this would not explain the better results that are obtained after September and the comparably good results from August 14 for Aqua. Further work is underway to understand this behavior.

Further understanding of the Aqua MODIS results can be gained when comparing the average percent difference between the vicarious results and sensors with similar spectral bands. This is shown in Figure 8 in which the average percent difference between Landsat-7 ETM+ and the vicarious results is shown along with the average percent difference for Aqua and Terra MODIS. The Landsat-7 ETM+ results are the average of 39 data sets collected during the period between June 1999 and May 2003. The Terra MODIS results are for the period between April 2000 and September 2002 and consist of 12 data sets. All of the Terra MODIS results are for Railroad Valley, while the ETM+ results contain data sets from all test sites used by the RSG. The Aqua MODIS values are based on the data shown previously. The bars for each sensor indicate the standard deviation about the average for each data set.

The key points to note in Figure 8 are that the standard deviations for the Aqua MODIS sensor are typically larger than those of the Terra MODIS and the averages are higher in general than those of

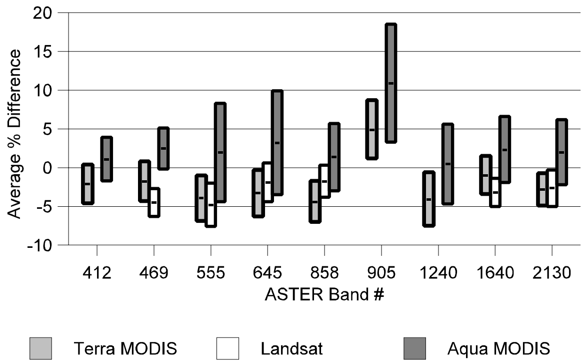

Figure 8. Average percent difference and standard deviation between vicarious predictions and reported sensor radiance for ETM+ and both MODIS sensors.

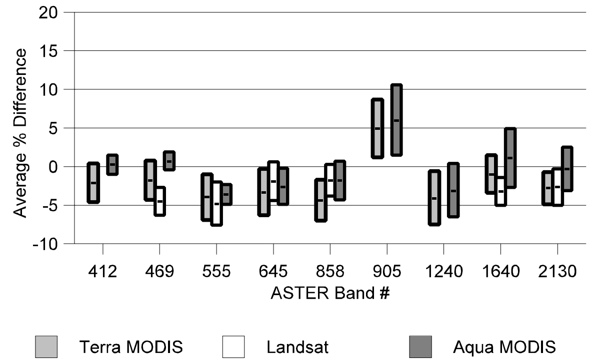

Figure 9. Same as Figure 8 except values for Aqua MODIS are determined from the five data sets collected after September 22.

Terra MODIS and ETM+. The larger standard deviation is of interest since the Terra MODIS data set and Aqua MODIS data set consist of nearly the same number of points and similar measurement conditions.

Limiting the Aqua results to include only the five dates after September 22 significantly reduces the standard deviation as well as causes the average percent difference to agree much better with ETM+ and Terra MODIS (see Figure 9). Of interest is also the relatively good agreement between the vicarious and reported radiances with all averages (except 905 nm for Aqua MODIS) in Figure 9 being within 5% of the vicarious predictions. It is not clear at this point the cause of the odd behavior of the 905-nm band for both Terra and Aqua MODIS, but one suspected cause is a bias in the surface measurements due to water vapor absorption.

As mentioned earlier, one of the primary reasons for monthly campaigns to Railroad Valley Playa has been to maintain meteorological equipment and a Cimel sunphotometer. The meteorological instrumentation includes wind speed and direction, temperature, pressure, humidity, and rainfall. In addition a pyranometer is also part of the data collection. A key measurement that has been missing in the past as part of the meteorological data collection has been a characterization of the surface reflectance. The surface reflectance of RRV is not constant with time due to changing surface moisture conditions. Thus, monitoring the reflectance from the ground would greatly improve any use of RRV as a cross-calibration site. We have begun work to develop a set of ground-looking, robust multispectral radiometers that will be deployed continuously on the site. The radiometers will rely on LED-based detectors that reduce the cost of the instruments and the overall stability of the radiometers and the cost of building these radiometers will be funded through other projects.

Testing of the radiometers has already begun and Figure 10 shows some early results from a prototype instrument deployed in January 2003. The goal is to create eight sets of three multispectral radiometers (a total of 24 radiometers) deployed that can sample the playa reflectance as a function of time to determine the effects of surface moisture. This effect is clear in Figure 10 which shows how the reflected radiance from the surface in comparison to rainfall events and upward looking pyranometer data. The difficulty, of course, will be to convert these measurements to reflectance. This work is currently underway to determine the best approach, but one candidate is to use the maintenance trips to evaluate the calibration of each radiometer set using the a solar-radiation-based calibration approach. This allows the data to be converted to absolute radiance and then the solar radiometer results will help predict the downwelling irradiance and then reflectance.

<u>Faculty, staff, and students</u>: The personnel associated with the RSG during the reporting period and receiving some level of funding from the RSG's EOS contract were as follows: Faculty: S.

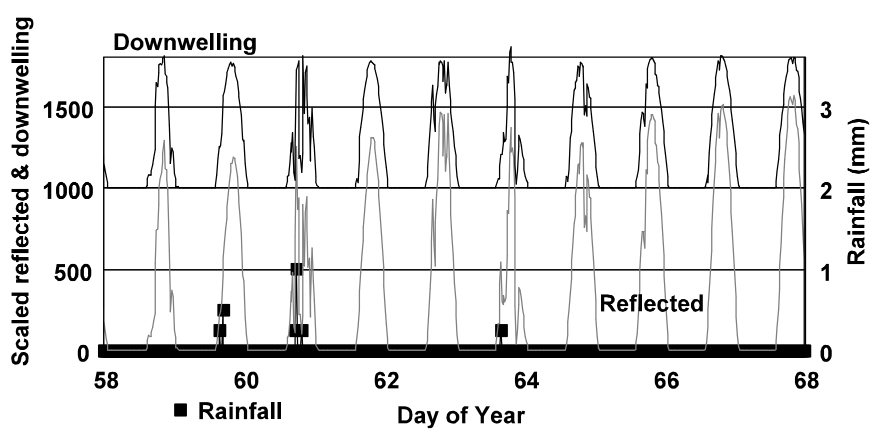

Figure 10. Graph of rainfall, downwelling pyranometer and reflected radiance at RRV test site for 2003

Biggar, C. Cattrall, K. Thome, and E. Zalewski. Staff: C. Burkhart, R. Kingston, R. Pylman, and S. Taylor. Students: N. Anderson (undergrad), K. Canham (undergrad), T. Chen (Ph. D.), J. Czapla-Myers (Ph. D.), W. Garland (Ph. D.), D. Moyer (M.S.), Q. Sanford, and C. Stratton (M.S.). Canham graduated with a B.S. degree in Optical Science, while Sanford and Stratton joined the group in January.